Chapter 2. Agricultural Tilling

The current version of AP-42 (i.e., the 5th edition) does not address agricultural tilling even though a PM10 emission factor for fugitive dust generated by agricultural tilling was developed by Midwest Research Institute in 1983 (see Appendix B) and adopted by the USEPA in their 4th edition of AP-42. Thus, the methodology adopted by the California Air Resources Board (CARB) is presented as the primary emissions estimation methodology in lieu of an official EPA methodology for this fugitive dust source category.

This section was adapted from Section 7.4 of CARB's Emission Inventory Methodology. Section 7.4 was last updated in January 2003.

2.1 Characterization of Source Emissions

The agricultural tilling source category includes estimates of the airborne soil particulate emissions produced during the preparation of agricultural lands for planting and after harvest activities. Operations included in this methodology are discing, shaping, chiseling, leveling, and other mechanical operations used to prepare the soil. Dust emissions are produced by the mechanical disturbance of the soil by the implement used and the tractor pulling it. Soil preparation activities tend to be performed in the early spring and fall months. Particulate emissions from land preparation are computed by multiplying a crop specific emission factor by an activity factor. The crop specific emission factors are calculated using operation specific (i.e., discing or chiseling) emission factors which are combined with the number of operations provided in the crop calendars. The activity factor is based on the harvested acreage of each crop for each county in the state. In addition, acre-passes are computed, which are the number of passes per acre that are typically needed to prepare a field for planting a particular crop. The particulate dust emissions produced by agricultural land preparation operations are estimated by combining the crop acreage and the operation specific emission factor.

2.2 Emission Estimation: Primary Methodology[1-5]

The particulate dust emissions from agricultural land preparation are estimated for each crop in each county using the following equation.

$$\text{Emissions}_{\text{crop}} = \text{Emission Factor}_{\text{crop}} \times \text{Acres}_{\text{crop}}$$

Then the crop emissions for each county are summed to produce the county and statewide PM10 and PM2.5 emission estimates. The remainder of this section discusses each component of the above equation.

Acres. The acreage data used for estimating land preparation emissions are based on the state summary of crop acreage harvested. The acreage data are subdivided by county and crop type for the entire state, and are compiled from individual county agricultural commissioner reports.

Crop Calendars and Acre-Passes. Acre-passes (the total number of passes typically performed to prepare land for planting during a year) are used in computing crop specific emission factors for land preparation. These land preparation operations may occur following harvest or closer to planting, and can include discing, tilling, land leveling, and other operations. Each crop is different in the type of soil operations performed and when they occur. For the crops that are not explicitly updated, an updated crop profile from a similar crop can be used. For updating acre-pass data, it is also useful to collect specific information on when agricultural operations occur. Using these data, it is possible to create detailed temporal profiles that help to indicate when PM emissions from land preparations may be highest.

Emission Factor. The operation specific PM10 emission factors used to estimate the crop specific emission factor for agricultural land preparations were initially extracted from a University of California Davis report.[4] After discussions with regulators, researchers, and industry representatives, the emission factors were adjusted based on a combination of scientific applicability, general experience, and observations. Five emission factors were developed by UC Davis using 1995 to 1998 test data measured in cotton and wheat fields in California. The operations tested included root cutting, discing, ripping and subsoiling, land planing and floating, and weeding, which produced emission factors that are summarized in Table 2-1 below. The PM2.5/PM10 ratio for agricultural tilling dust published by CARB is 0.222.[5]

Table 2-1. Land Preparation Operation Emission Factor

Land preparation operations	Emission factor (lbs PM10/acre-pass)
Root cutting	0.3
Discing, Tilling, Chiseling	1.2
Ripping, Subsoiling	4.6
Land Planing & Floating	12.5
Weeding	0.8

There are more than thirty different land preparation operations commonly used. With five emission factors available, the other operations can be assigned "best-fit" factors based on similar potential emission levels. The assignment of emission factors for operations are based on the expertise and experience of regulators, researchers, and industry representatives. For each crop, the emission factor is the sum of the acre-pass weighted emission factors for each land preparation operation.

Assumptions and Limitations. This methodology is subject to the following assumptions and limitations:

1. The land preparation emission factors for discing, tilling, etc., are assumed to produce the same level of emissions, regardless of the crop type.

2. The land preparation emission factors do not change geographically for counties.

3. A limited number of emission factors are assigned to all land preparation activities.

4. Crop calendar data collected for test area (i.e., San Joaquin) crops and practices were extrapolated to the same crops in the remainder of the state. Existing crop profiles were used for the small percentage of crops in which update information was not collected.

5. In addition to the activities provided in the crop calendars, it is also assumed that field and row crop acreage receive a land planing pass once every five years.

Temporal Activity. Temporal activity is derived by summing, for each county, the monthly emissions from all crops. For each crop, the monthly emissions are calculated based on its monthly crop calendar profile, which reflects the percentage of activities that occurs in that month. An example of the monthly profile for almonds, cotton, and wine grapes is shown below in Table 2-2. Because the crop composite differs by county, the monthly profiles for counties are different. An example of a composite county monthly profile for Fresno County is shown below in Table 2-3.

Table 2-2. Monthly Activity Profile of Selected Crops

Crops	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEP	OCT	NOV	DEC
Almonds	0	0	0	0	0	0	0	0	0	0	50	50
Cotton	0	9	9	0	0	0	0	0	0	0	41	41
Grapes-wine	0	0	0	4	16	16	12	12	12	28	0	0

Table 2-3. County Land Preparation Profile Composite

County	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEP	OCT	NOV	DEC
Fresno	3	6	6	2	2	1	3	4	2	12	30	29

2.3 Demonstrated Control Techniques

The emission potential of agricultural land preparation operations, including soil tilling, is affected by the soil management and cropping systems that are in place. Table 2-4 presents a summary of demonstrated control measures and the associated PM10 control efficiencies. It is readily observed that reported control efficiencies for many of the control measures are highly variable. This may reflect differences in the operations as well as the test methods used to determine control efficiencies.

Table 2-4. Control Efficiencies for Control Measures for Agricultural Tilling[6-10]

Control measure	PM10 control efficiency	References/Comments
Equipment modification	50%	MRI, 1981. Control efficiency is for electrostatically charged fine-mist water spray.
Limited activity during a high-wind event	1 - 5%	SCAQMD, 1997. Control efficiency assumes no tilling when wind speed exceeds 25 mph.
Reduced tillage system (Conservation Tilling)	35 - 50%	Coates, 1994. This study identified total PM10 emissions generated for five different cotton tillage systems, including conventional tilling. Four of the systems combine several tillage operations (e.g., shredding, discing, mulching).
	60%	MRI, 1981. Control efficiency is for a minimum tillage technique that confines farm equipment and vehicle traffic to specific areas (for cotton and tomatoes).
	25 - 100%	MRI, 1981; U.S. EPA, 1992. Control efficiency is for application of herbicide which reduces need for cultivation (i.e., 25% for barley, alfalfa, and wheat; 100% for cotton, corn, tomatoes, and lettuce).
	30%	MRI, 1981; U.S. EPA, 1992. Control efficiency is for laser-directed land plane which reduces the amount of land planing.
	50%	MRI, 1981; U.S. EPA, 1992. Control efficiency is for using “punch” planter instead of harrowing (for cotton, corn, and lettuce).
	50%	MRI, 1981. Control efficiency is for using “plug” planting that places plants more exactly and eliminates the need for thinning (for tomatoes, only).
	50%	MRI, 1981; U.S. EPA, 1992. Control efficiency is for aerial seeding which produces less dust than ground planting (for alfalfa and wheat).
	91 - 99%	Grantz, et al. 1998. Control efficiency is for revegetation of fallow agricultural lands by direct seeding.
Tillage based on soil moisture	90%	MRI, 1981; U.S. EPA, 1992. Control efficiency is for sprinkler irrigation as a fugitive dust control measure. Also, sprinkler irrigation could reduce the need for extensive land planing associated with surface irrigation.
Sequential cropping	50%	MRI, 1981. Control efficiency is for double cropping corn.
Surface roughening	15 - 64%	Grantz et al, 1998. Control efficiency is for increasing surface roughness using rocks and soil aggregates.

2.4 Regulatory Formats

Fugitive dust control options have been embedded in many regulations for state and local agencies in the WRAP region. Regulatory formats specify the threshold source size that triggers the need for control application. Example regulatory formats for agricultural tilling downloaded from the Internet for several local air quality districts in California (www.arb.ca.gov/drdb/drdb.htm) are presented in Table 2-5.

Table 2-5. Example Regulatory Format for Agricultural Tilling

Control measure	Goal	Threshold	Agency
Pre-activity requirements: pre-watering, phasing of work, applying water during active ops	Limit visible dust emissions to 20% opacity		SJVAPCD Rule 8021 11/15/2001
Implement one of following during inactivity: restricting vehicle access or applying water or chemical stabilizers	Sets stabilization requirements		SJVAPCD Rule 8021 11/15/2001
Use mowing or cutting instead discing and maintain at least 3" stubble above soil (Also requires pre-application of watering if discing for weed abatement			SCAQMD Rule 403 12/11/1998
Cease of tilling or mulching		Wind speeds greater than 25 mph	SCAQMD Rule 403.1 1/5/1993 (Coachella Valley)

2.5 Compliance Tools

Compliance tools assure that the regulatory requirements, including application of dust controls, are being followed. Three major categories of compliance tools are discussed below.

Record keeping: A compliance plan is typically specified in local air quality rules and mandates record keeping of source operation and compliance activities by the source owner/operator. The plan includes a description of how a source proposes to comply with all applicable requirements, log sheets for daily dust control, and schedules for compliance activities and submittal of progress reports to the air quality agency. The purpose of a compliance plan is to provide a consistent reasonable process for documenting air quality violations, notifying alleged violators, and initiating enforcement action to ensure that violations are addressed in a timely and appropriate manner.

Site inspection: This activity includes (1) review of compliance records, (2) proximate inspections (sampling and analysis of source material), and (3) general observations (e.g., observation of visible dust plume). An inspector can use photography to document compliance with an air quality regulation.

On-site monitoring: EPA has stated that "An enforceable regulation must also contain test procedures in order to determine whether sources are in compliance." Monitoring can include observation of visible plume opacity, surface testing for crust strength and moisture content, and other means for assuring that specified controls are in place.

Compliance tools applicable to agricultural tilling are summarized in Table 2-6.

Table 2-6. Compliance Tools for Agricultural Tilling

Record keeping	Site inspection/monitoring
Tilling equipment types, activities, frequencies, speeds, and dates.	Observation of dust plumes during periods of agricultural tilling.

2.6 Sample Cost-Effectiveness Calculation

This section is intended to demonstrate how to select a cost-effective control measure for agricultural tilling. A sample cost-effectiveness calculation is presented below for a specific control measure (conservation tilling) to illustrate the procedure. The sample calculation includes the entire series of steps for estimating uncontrolled emissions (with correction parameters and source extent), controlled emissions, emission reductions, control costs, and control cost-effectiveness values for PM10 and PM2.5. In selecting the most advantageous control measure for agricultural tilling, the same procedure is used to evaluate each candidate control measure (utilizing the control measure specific control efficiency and cost data), and the control measure with the most favorable cost-effectiveness and feasibility characteristics is identified.

Sample Calculation for Agricultural Tilling

Step 1. Determine source activity and control application parameters.

Field size (acres)	320
Frequency of operations per year	4
Control Measure	Conservation tilling
Control application/frequency	Reduce 4 passes to 3 passes
Control Efficiency	25%

The field size and frequency of operations are assumed values, for illustrative purposes. Conservation tilling has been chosen as the applied control measure. The control application/frequency and control efficiency are values determined from the proportional reduction in tilling frequency.

Step 2. Calculate Emission Factor. The PM2.5 and PM10 emission factors are obtained from CARB, 2003.[11]

PM2.5 Emission Factor	0.27 (lb/acre-pass)
PM10 Emission Factor	1.2 (lb/acre-pass)

Step 3. Calculate Uncontrolled PM Emissions. The emission factors (given in Step 2) are multiplied by the field size and the frequency of operations (both under activity data) and then divided by 2,000 lbs to compute the annual emissions in tons per year, as follows:

Annual emissions = (Emission Factor x Field Size x Frequency of Ops)/2,000

- Annual PM10 Emissions = (1.2 x 320 x 4)/2,000 = 0.77 tons
- Annual PM2.5 Emissions = (0.27 x 320 x 4)/2,000 = 0.17 tons

Step 4. Calculate Controlled PM Emissions. The uncontrolled emissions (calculated in Step 3) are multiplied by the percentage that uncontrolled emissions are reduced, as follows:

Controlled emissions = Uncontrolled emissions x (1 – Control Efficiency), where CE = 25% (as seen under activity data)

For this example, we have selected conservation tilling as our control measure. Based on a control efficiency estimate of 25%, the annual controlled emissions are calculated to be:

Annual Controlled PM10 emissions = (0.77 tons) x (1 – 0.25) = 0.58 tons
Annual Controlled PM2.5 emissions = (0.17 tons) x (1 – 0.25) = 0.13 tons

Step 5. Determine Annual Cost to Control PM Emissions.

The Annualized Cost of control is calculated by reducing the number of tilling passes from 4 to 3. The cost of tilling is assigned a value of $10 per acre (WSU, 1998[12]). The number of acres is multiplied by $10:

Annualized Cost = 320 x 10 = –$3,200

The annualized cost is negative, because the amount shown is considered to be saved, not spent.

Step 6. Calculate Cost-effectiveness. Cost-effectiveness is calculated by dividing the annualized cost by the emissions reduction. The emissions reduction is determined by subtracting the controlled emissions from the uncontrolled emissions:

Cost-effectiveness = Annualized Cost/ (Uncontrolled emissions – Controlled emissions)

Cost-effectiveness for PM10 emissions = $3,200/ (0.77 – 0.58) = –$16,700/ton
Cost-effectiveness for PM2.5 emissions = $3,200/ (0.17 – 0.13) = –$80,000/ton

The negative cost-effectiveness values indicate a cost savings.

2.7 References

1. Flocchini, R. G., James, T. A., et al., 2001 *Sources and Sinks of PM10 in the San Joaquin Valley,* Interim Report for United States Department of Agriculture Special Research Grants Program.

2. California Agricultural Statistics Service, 2002. 2000 acreage extracted from agricultural commissioner's reports, Sacramento, CA. December.

3. Gaffney, P. H., Yu, H., 2002. *Agricultural Harvest: Geologic Particulate Matter Emission Estimates,* Background Document prepared by the California Air Resources Board. December.

4. Cassel, T., 2002. *Evaluation of ARB application of UCD emission factors,* prepared for San Joaquin Valley Ag Tech Committee. July 12.

5. Houck, J., 1989. *Determination of Particle Size Distribution and Chemical Composition of Particulate Matter from Selected Sources in California*, Final Report prepared for CARB by OMNI Environmental Services, Inc., June 30.

6. Coates, W., 1994. *Cotton Tillage/Quantification of Particulate Emissions*, Final Report prepared for Arizona Department of Environmental Quality Air Assessment Division by the University of Arizona Tucson.

7. Grantz, D.A., Vaughn, D.L., R.J., Kim, B., VanCuren, T., Campbell, D., 1998. California Agriculture, Vol. 52, Number 4, Pages 8-13. July-August.

8. MRI, 1981. *The Role of Agricultural Practices in Fugitive Dust Emissions*, Draft Final Report prepared for California Air Resources Board by Midwest Research Institute, Project No. 4809-L. April 17.

9. SCAQMD, 1997. *Air Quality Management Plan, Appendix IV-A: Stationary and Mobile Source Control Measures, CM#97BCM-04*, South Coast AQMD, Diamond Bar, CA. February.

10. U.S. EPA, 1992. *Fugitive Dust Background Document and Technical Information Document for Best Available Control Measures.* U.S. Environmental Protection Agency, Office of Air and Radiation , Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. September.

11. CARB, 2003. *Emission Inventory Procedural Manual Volume III: Methods for Assessing Area Source Emissions,* California Air Resources Board, Sacramento, CA. November.

12. WSU, 1998. *Farming with the Wind*, Washington State University College of Agriculture and Home Economics Miscellaneous Publication N. MISC0208. December.